RBF Morph software
RBF mesh morphing ACT extension for ANSYS Mechanical

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• Company Introduction
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• Fluent Adjoint Coupling
RBF Morph is a pioneer and world-leading provider of numerical morphing techniques and solutions conceived to efficiently handle shape optimization studies concerning most challenging industrial applications. We are an independent software-house and vendor. Our main product is **RBF Morph™**, that is a unique morpher that combines a very accurate control of the geometrical parameters with an extremely fast mesh smoothing properly designed to be integrated in advanced computational optimization procedures.

The **RBF Morph** tool is currently available in the market mainly as add-on of the CFD commercial code ANSYS® Fluent®.
The RBF Morph tool had its inception in 2008 as an on-demand solution for a Formula 1 top team. The need was a novel technology able to change the shape of large CFD numerical models as fast as possible. The final result had been so good that the technology was packaged in a commercial software product and launched onto the market.

At present, Dr. Marco Evangelos Biancolini is the unique owner of the RBF Morph technology and, as Director, avails himself of the collaboration of several experts for the deliver of products and services.
Company Introduction

- Morphing-based numerical tools and services
- RBF Morph Milestones
  - 2008: tool implementation for Formula 1 top team consultancy activity
  - 2009: founded in Italy
  - 2009: Software Partner of ANSYS
  - 2009: at EASC RBF Morph won the Most Advanced Approach Award Most Innovative Approach using Simulation Methods
  - 2011: strategic partnership with Tor Vergata University (Rome)
  - 2012: OEM partner of ANSYS
  - 2013: beneficiary of an FP7 AAT Project RBF4AERO
  - 2013: at ASWC RBF Morph awarded for the Best use of HPC
  - 2013: Partner of Enginsoft
  - 2014: beneficiary of FP7 Project RIBES
  - 2014: beneficiary of FP7 Fortissimo
RBF Morph software line
Mesh Morphing with RBF

- A system of **Radial Basis Functions** is used to fit a solution for the mesh movement/Morphing, from a list of source points and their displacements.

- The RBF problem definition does not depend on the mesh

- Radial Basis Function interpolation is used to derive the displacement in **any location** in the space, each component of the displacement is interpolated:

\[
\begin{align*}
v_x &= s_x(x) = \sum_{i=1}^{N} \gamma_i^x \phi\left(\left\| x - x_{ki} \right\| \right) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\
v_y &= s_y(x) = \sum_{i=1}^{N} \gamma_i^y \phi\left(\left\| x - x_{ki} \right\| \right) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\
v_z &= s_z(x) = \sum_{i=1}^{N} \gamma_i^z \phi\left(\left\| x - x_{ki} \right\| \right) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z
\end{align*}
\]

- RBF are recognized as one of the **best mathematical tool** for mesh morphing. The main issue is about performances required for the solution of large dataset.
• HPC RBF **general purposes** library (state of the art algorithms, parallel, GPU). This is the numerical kernel of our software. **Millions** of RBF centers can be fitted in a short time.

• Awarded mesh morphing software available as an add-on for **ANSYS Fluent** CFD solver

• **Stand alone** morphing software + smoothing commands for different mesh formats

• ANSYS Mechanical **ACT module** (first beta version already working since June 2014)
- **Add on** fully integrated within **Fluent** (GUI, TUI & solving stage), **Workbench** and **Adjoint Solver**

- **Mesh-independent** RBF fit used for surface mesh morphing and volume mesh smoothing

- **Parallel** calculation allows to morph **large size** models (many millions of cells) in a short time

- Management of **every kind of mesh** element type (tetrahedral, hexahedral, polyhedral, etc.)

- Support of the **CAD re-design** of the morphed surfaces

- **Multi fit** makes the Fluent case truly parametric (only 1 mesh is stored)

- **Precision**: exact nodal movement and exact feature preservation (**RBF** are better than **FFD**)
Deeply integrated in ANSYS Mechanical: same look & feel, same interaction logic

Nested in the usual Mechanical tree as an added object, shares its scoping tools for geometrical and mesh elements selections

Written in python and xml, uses external RBF Morph core libraries

Child hierarchical logic for complex morphings (two steps, three steps, …, n steps setups)
• RBF solutions are fully compatible and **exchangeable** between add-on and standalone versions

• Support for STL and CGNS file formats. Selected morphed surfaces can be exported in STL format and **back to CAD** is possible via STEP files

• **Add-on-like** interface

• **Solver independent** process currently supports many mesh formats

• Functions **scriptable** via tcl

• Global supported bi-harmonic functions and $C^0$, $C^2$, $C^4$ compact supported functions available
Ongoing RBF Morph Researches
Ongoing RBF research

- RBF Morph and Adjoint coupling: Adjoint sculpting, Adjoint preview, Augmented DOE
- **STL** targeting, **CAD** controlled surfaces
- **Mesh to CAD** features
- Mapping of **magnetic** and **pressure** loads
- Interpolation of **hemodynamic** flow fields acquired *in vivo*
- Strain and **stress calculation** (experimental data, coarse FEM, isostatic lines)
• “Innovative Benchmark Technology for Aircraft Engineering Design and Efficient Design Phase Optimisation” – ACP3-GA-2013-605396

• www.rbf4aero.eu
• **Radial basis functions at fluid Interface Boundaries to Envelope flow results for advanced Structural analysis**

**JTI-CS-2013-GRA-01-052**
• Factories Of the Future Resources, Technology, Infrastructure and Services for Simulation and Modelling

• Approved experiment: “Virtual Automatic Rapid Prototyping Based on Fast Morphing on HPC Platforms”
RBF mesh morphing ACT extension for ANSYS Mechanical
Why mesh morphing?

• It allows to have parametric shape mesh that preserves the original topology. **Remeshing noise** is avoided.

• It allows to update the shape of a **validated FEM model** without rebuilding a new mesh.

• New shapes can be investigated even if the underlying **CAD geometry** is missing.

• The mesh can be updated to measured shapes (i.e. accounting for **manufacturing tolerances**) 

• It’s usually faster than remeshing.
Why RBF morphing?

- RBF Morph is a best in class product crafted to deal with challenging CFD application (huge meshes)
- 7 years of experience on industrial applications of Radial Basis Functions (RBF)
- RBF are recognized as one of the best mesh morphing tool available in the industrial and scientific community
- A new vision (we have started the new project from scratch) to put in the hands of ANSYS Mechanical Users the fastest and easiest mesh morphing tool
- Satisfy the needs of many users asking for such a kind of technology available in ANSYS Mechanical
ACT module specs

- Fully **embedded** in ANSYS Mechanical with same “look & feel”
- Integration in the tree and founded on the working principles of **ANSYS Workbench**
- Based on the ACT (Application Customization Toolkit) **extension** concept
- Geometrical and mesh scoping to set-up the mesh morphing problem
- Parametric (coming soon! In ANSYS 16 ACT modules parameters will be exposed natively)
- RBF **fast solver** (including parallel and GPU support)
ACT module specs

• Easy to use, flexible and expressive.

• Powered by multi-step RBF technology (which effectiveness has been extensively proven in RBF Morph)

• RBF fitting and mesh morphing happen as a unique HPC process at each shape update. This allows the maximum flexibility with respect to parameterization

• RBF component set-up data stored and persistent with the ANSYS Mechanical project.

• Advanced interaction with DM to enable CAD resynchronization after morphing (coming soon)
• **Hierarchical** multi-step RBF approach

• Each morphing **target** can be controlled using the superposition of a constant translation (other modifiers will be introduced) and an RBF field generated by its **sources** (if any)

• **Source points** are extracted using the motion of all the children

• If the child is a leaf its movement is known otherwise it **becomes a target** and has to be solved descending the tree

• Sounds complicated? Let’s explain it with an example!
• A simple **cube** is loaded on the top and clamped to the bottom

• **Structural mechanics** tell us that this structure can be optimized adopting a tapered profile

• A parabola is obtained if we look for constant **bending stress** beam

• The theory is well known in gear design as the **Lewis formula** used for the stress assessment of a teeth
Cube example

• Boundary conditions

A: Static Structural
Force
Time: 1 s
21/05/2014 09:03

A: Fixed Support
B: Force: 1e+007 N
- Baseline solution
• First morphing set-up!
Cube example

- The first level set **Cube** (volume scoping) define the mesh to be morphed. Controlled by ground and top.

- At second level (surface scoping) we have two sets: **ground** (fixed and leaf of the tree) and **top** (controlled by Side1 and Side2).

- At third level (edge scoping) we have **Side1** (fixed) and **Side2** (moving in negative X direction).
• Morphed solution #1
• Second morphing set-up!
Cube example

- The previous set-up has been refined and now we have a fourth level (scoping points and nodes) to control the shape of **Side2** that is controlled by Lateral Points and Central Points.

- Individual movements are imposed in the negative X direction to **Lateral Points** and **Central Points**.

- At this level it would be good to control curvature changing the **order** of RBF function (coming soon!)
Cube example

- Morphed solution #2

A: Static Structural
- Equivalent Stress
- Type: Equivalent (von-Mises) Stress
- Unit: Pa
- Time: 1
- 21/05/2014 09:26

1.1785e8 Max
1.051e8
9.2355e7
7.9609e7
6.6862e7
5.4115e7
4.1368e7
2.8621e7
1.5874e7
3.1276e6 Min

0,000 0,450 0,900 m
0,225 0,675
Cube example

- The set-up #1 and #2 are explained in detail.
- The set-up can be further enriched to fulfill the desired shape.
- Some example follows…
Cube example

Child Entity
21/05/2014 20:28

Child Entity 2
Cube example

Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
21/05/2014 20:30

1.0646e8 Max
9.526e7
8.4059e7
7.2858e7
6.1657e7
5.0456e7
3.9256e7
2.8055e7
1.6854e7
5.6531e6 Min
• Mass reduction 36% Stress reduction 12%
This is a simple mesh morphing feasibility study for a geometry relevant for SACMI.

Part studied is a quarter of the basement of a press.

Area to be optimized is the one highlighted in green.

Simple boundary conditions are used to stress the part (red fixed, yellow symmetry, blue loaded).
Mesh morphing has been used to reduce the stress concentration acting on the shape of the fillet.
• As the fillet is smoothed a stress redistribution is observed.
• Notice that high mesh deformation is properly accommodated thanks to RBF mesh morphing

Morph #3
• Original vs. Optimised (13% reduction of stress peak)
Conclusions

• A novel mesh morphing tool has been implemented in **ANSYS Mechanical** using ACT extension technology

• **Radial Basis Functions** are used for multistep set-up

• The new software benefits of past experience on RBF Morph **ANSYS Fluent** add-on (mainly CFD)

• Nevertheless we have restarted all the developments **from scratch** i.e. reusing **knowledge** and **ideas** (no cross compatibility between tools)

• Basic capability of the first software prototype are demonstrated on a simple FEM mesh and on an **industrial FEM model**

• **How can we do better? Please do not hesitate to tell us your needs!**
ご清聴ありがとうございました

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